Astronomy Cast Episode 196
Luminosity & Magnitude

Fraser: Astronomy Cast Episode 196 for Monday June 28, 2010, Luminosity & Magnitude. Welcome to Astronomy Cast, our weekly facts-based journey through the cosmos, where we help you understand not only what we know, but how we know what we know. My name is Fraser Cain, I'm the publisher of Universe Today, and with me is Dr. Pamela Gay, a professor at Southern Illinois University Edwardsville. Hi, Pamela, how are you doing?

Pamela: I'm doing well, how are you doing, Fraser?

Fraser: I'm doing very well. So, I think we're going to...

Pamela: Give in to summer?

Fraser: Give in to summer. This is the last episode of the summer. The date on this is June 28... we're going to take July and August off. And by "going to," I mean we already did, and now we're just going to make it official. So, no episodes from June 28 until the beginning of September, and then we're going to be doing DragonCon, and we're going to try to do a live show there. We will do a live show there... Then, regular schedule will continue after that when your summer travel schedule eases up.

Pamela: We're going to be bringing you back the Question Shows, and we're going to try very, very hard to get back to our old... we launch on Mondays... we launch on Thursdays.

Fraser: Yeah.

Pamela: We're going to try... it's a goal.

Fraser: It's a goal.... it's a dream. So DragonCon... Labor Day weekend... in Atlanta. Both of us are going to be there. We're going to be doing a live version of Astronomy Cast, and we're going to be on a bunch of other panels. We will be... we're going to have t-shirts, CDs, so if you want to come and hang and meet us and go for beer, we'll be there. That'll be great.

Pamela: We're hoping that all of you will come and get Astronomy Cast t-shirts. They're pretty!

Fraser: They're pretty cool. I like them, actually.

Pamela: Yeah, Luke Hayes did our CDs and Justin Ogleby did our t-shirts. And we love all of our wonderful creative listeners like those two.

Fraser: Oh and then also Thursday night, on the 2nd... is that right?

Pamela: Yes.

Fraser: We have the star party?

Pamela: Yes... Maria Walters, one of the skepchicks, is arranging a Moon Over Cancer star party to raise money to help defeat cancer in the name of the Blue Collar Scientist, Jeff Metcalf. Fraser and I will be there. I'll be giving a talk on citizen science. We hope that the rest of you will come and help us raise money for the American Cancer Society.

Fraser: And there's some information on the Atlanta Skeptics website and also on DragonCon, too... on their site. And I'm sure we'll have some links in the Show Notes. Ok, alright, well let's get on with the show, then. Astronomers measure the brightness of stars as magnitude. But this brightness depends on the distance to the star as well as the total amount of energy it's pumping out into space. From our vantage point here on

Earth, appearances can be deceiving. So let's get some terminology out of the way. What's luminosity?

Pamela: It is a measure of how much flux of photons... how many photons per square meter measured in units of energy are coming off of an object.

Fraser: And then magnitude?

Pamela: Magnitude is a way of taking that linear set of numbers and transforming it into what your eyes see. So if you double the number in luminosity, the number of photons doubles. If you double the number in magnitude systems, it's some crazy logarithmic scaling craziness.

Fraser: But the point being that there's two kinds of magnitude, right... there's absolute magnitude and apparent magnitude.

Pamela: Yes. And both of those have this crazy non-linear way of looking at the numbers. But the apparent magnitude system is how bright something actually looks in the sky. You look up, you see it, you go... oh, that's magnitude 3. But absolute magnitude is kind of like the number you read on a light bulb box. If you're a mile away from the light bulb, it's not that bright. If you are right next to the light bulb, it's really bright. But in both cases, it's going to be the same luminosity... the same absolute magnitude that it says on the box... 100 Watts, or whatever.

Fraser: Why does this matter?

Pamela: Well, if you're trying to figure out how to compare two objects... if I'm looking in the sky at a really close nearby average mundane star, it might appear to be the same brightness as ginormous, giant, universe-devouring... not really, they don't do that... giant hundred solar mass star that's on the other side of the galaxy from us.

Fraser: Right, some of the closest stars are invisible, and some of the brightest stars are the most distant. Yet in the sky...

Pamela: They appear the same.

Fraser: It's hard to tell them apart. Yeah, yeah....

Pamela: And that's apparent brightness.

Fraser: Right.

Pamela: So, if I want to make a meaningful comparison of these two objects, that's where luminosity comes in. That's where absolute magnitude comes in. Absolute magnitude is the number you get if both objects were ten parsecs... about 30 light years... away from you.

Fraser: So I've seen the magnitude system before. There's a number associated with the brightness of all of the objects. The moon has this magnitude... the sun has that magnitude. The dimmest stars visible with the unaided eye have such and such magnitude.

Pamela: Six.

Fraser: So where does this... don't give it away! So, where does this numeric system come from? What's the history of this?

Pamela: Well, it was first documented by Ptolemy and it probably came originally from Hipparchus. The system starts with the rather simple... let's take the brightest stars in the sky, call them magnitude 1. Take the faintest stars in the sky, call them magnitude 6 and build in between where from 1 to 2 is roughly a doubling. From 2 to 3 is roughly a doubling according to your eyeball. Now our eyeballs are not linear systems. This is the problem. What your eye sees as twice as bright, your little detector that you have for your camera won't. But it was a system to start with. It got worked with for a long time and then it was realized... well, you know, maybe there's a bunch of stuff out there that's even brighter. Then the system got reworked with the star Vega, which is one of the brightest Northern Hemisphere stars, but not the brightest just one of the brightest. It got redone as magnitude zero. We based the entire system on magnitude zero at a given time through a given detector through a given filter set. Now we realize that Vega is actually magnitude 0.03. Good enough. So the system is based on Vega – zero; faintest thing your human eye can see under normal dark skies, unless you're a super human person... Steve O'Meara can see fainter than that, that's magnitude six. In most big cities you can see magnitude 4.

Fraser: So, I guess in the olden days, this was all done visually... and that must have been really open to interpretation. Everybody's eyes are a little different. Trying to say that this star is brighter and that star is dimmer, I think it's a 4... I think it's a 5... 5.2! It must have been a really inexact science. Then, now, we have these modern instruments, right, where a CCD can tell you exactly how many photons are falling on it and give you an exact measurement.

Pamela: Well, the crazy thing is how inexact it wasn't! The human eye is a very accurate measure as long as you have things that you know their brightness. So you start with Vega; you label it zero. Then you move your way across the sky, labeling things that are known standards. Now, if you can get a bunch of people to agree on a handful of stars scattered across the sky, and their brightnesses, it's possible to work your way down from that. And what organizations like the American Association of Variable Star Observers have found is that human beings, if they're looking at objects nearby on the sky, and they know that this one's magnitude 12.4... well, that would be binoculars... this one's magnitude 3.4, this one over here is 3.9, this one over here is 3.2... what's this one in the middle? It's in the 3-range as well. They can, in the case of the best observers, get it accurate down to an extra decimal point. It's 3.46. And there's some error in that, but they're tracking the CCD measurements. So if you take the best observers and you average their measurements together, and then compare it to a CCD, you can see all the same nuances in a light curve.

Fraser: So then as you say, the magnitude scale is a doubling of light. So to go from six to five, you're seeing twice as much light coming from the star.

Pamela: So, this is where what you perceive differs from reality. It's really a logarithmic system, so the reality is, between a magnitude one star and a magnitude six star, there's a factor of 100 times in the actual light coming off of it.

Fraser: And astronomers have then added all of the objects into this scale. So things can be a lot brighter than zero, and this is where it gets kinda weird, and things can be a lot dimmer than six.

Pamela: Right. It turns out that really bright stars like Sirius, they end up with negative magnitudes. It's always curious to say well, Sirius is the brightest star and it has a magnitude of -1.4. Only in astronomy would that happen. The sun, it's a magnitude -26.7. Full moon, again, -12.7. We like point sevens, apparently. But then faint objects... the Hubble Space Telescope... it can at its deepest magnitudes, according to some of the websites I've looked at, get down to magnitude 30. So the idea that these really high numbers are really faint objects is a little bit brain breaking when you're first learning how to do the magnitude system.

Fraser: So if we could start it all over again, somebody would set the sun as zero and go up from there... or backwards.

Pamela: I don't know the best way to set it. So the problem is we're used to higher numbers means bigger. So does that mean that you start off by setting the sun as a million and work your way backwards? How do we do that so that we get the ordering correct? We just don't know that. It's a confused system, but trying to come up with a replacement system for the human eye is something we don't quite know how to do. This is where radio astronomers... your eye never saw in radio... so they can take certain liberties without confusing people. They simply count photons. They talk about how many Janskies... how much energy they got... in a perfectly linear system.

Fraser: But they do that on the high end of the scale, too, with gamma rays and they're getting shot by bullets... you can really feel them... as opposed to just how much light there is.

Pamela: Right. So there you start talking about how many electron volts, how many mega electron volts, you have coming from an object. So, depending on what part of the electromagnetic spectrum you're in, we like to switch our units up. When you fall into that optical range where the human eye can see, not only do we switch up our units, but we change the scale entirely. It's awkward.

Fraser: Right, and there are a few problems with this. The luminosity is the total amount of energy being fired out from this body, from this star. How much is it emitting in all wavelengths, right? While the magnitude is just the measurement of it individual.

Pamela: And magnitudes, we use different filters. It originated with the human eye, which we now call the V-filter... the visual filter. We've figured out how to take glass and change the glass' properties so that the light that passes through the glass is similar in characteristic to the amount of light and the colors of light that your eye perceives. But then we also like to look at objects using red filters that highlight things like Mira variables and distant galaxies. We like to look at things with blue filters that highlight star formation. All these different filters you get a different magnitude... you get a different amount of light coming through the filter depending on the color of the object. An object's temperature decides what color it is. So it's a vary complicated system. With Vega, they pegged it at zero in several different colors. But then when we talk about luminosity, that's all the colors and in magnitude we do use this work "bolometric" to refer to the bolometric magnitude is the magnitude the object would have if you could measure its light in every single wavelength.

Fraser: Right, ok... so the bolometric magnitude... that's a way to get a sense of what a star would look like if you could see with your eyeballs in every wavelength. So that kind of solves that problem. But the other big problem that we have with magnitude is that distance is everything. We look at a star in the sky and we see it at a certain level of brightness, but that doesn't tell you at all how bright it truly is. So how do astronomers figure this out?

Pamela: Well, we do lots of calculations. Luckily, there's certain stars that are close enough that we can tell just by the Earth's motion from June to December, as we go from one side of the sun's orbit to the other, we can tell how far away they are by how they appear to move against distant background galaxies. This is the same way you might measure the distance to your television set by blocking the television set out first with your thumb looking at it with your left eye, and then closing your left eye and opening your right eye and seeing how much your thumb moved. That will give you, rather, not the distance to your television, but the distance to your thumb. The television is a distant non-moving object, and you can see the angle your thumb moves, you can measure with a ruler the separation between your two pupils. Then, if you like trigonometry, you can then calculate how far away your thumb was when you made these measurement.

Fraser: Everybody do this right now! I don't care if you're in a bus... where you are... stick your arm out, put your thumb up, and then just switch eyeballs, and look at how your thumb moves back and forth against the background. And you can calculate the distance to your thumb that way.

Pamela: And so we use that principle with stars and distant galaxies. Instead of eyeball to eyeball, we do Earth's orbit on one side of the sun to Earth's orbit on the other side of the sun. Once we know the distance to an object, and once we know how bright it appears, thanks to physics we know how the light changes with distance. It actually... as the distance goes up, it goes as the square of the distance. So if something goes from one foot away from me to three feet away from me, I'll actually get one ninth the amount of light from that object. Using that physics of calculating how the amount of light we receive changes with changing distance, we're able to build up a picture of... ok, that object at that known distance has this absolute magnitude, this actual luminosity. This other type of object... it's completely different, but now I know with this other type of object that I can also measure its distance, I can also measure its brightness, I can calculate its luminosity. So we build up this picture of what all these different objects look like. And when we're lucky, we look at the same type of object 30 times, and its always exactly the same. Unfortunately, that doesn't happen very much. That pretty much happens for standard candle objects... things like RR Lyrae stars, Cepheid variable stars, Type IA supernovae, which luckily haven't gone off close enough that we can measure them via parallax. But we've been able to calibrate those using Cepheids and RR Lyraes. We start to build a picture one object at a time, getting more and more distant in the universe, of standard candles. Then we start going... ok, this object I don't understand is orbiting this object I do understand. So now I know its brightness and luminosity, thanks to calculations, as well.

Fraser: But, you cannot use the brightness or magnitude to determine its distance. You have to get at the distance some other way, and then once you have that, and you know its current brightness, you can then calculate how bright it really is... its luminosity. And its absolute magnitude.

Pamela: Yeah. Getting at distances is one of the most important and most difficult things we do in astronomy. It's so hard to measure distances. We actually did, I believe, an entire show dedicated to distances. And if I hallucinated this, we'll record that next.

Fraser: No, no it's one of our early ones... Measuring Distance in the Universe. And it's like this ladder, right, with up close you've got one method, and then you've got your next method of measuring distance, and they kind of overlap and that's how you know. You use one to validate the other one. You keep going up this ladder, all the way out to being able to measure to the very edge of the universe.

Pamela: It's amazing how we build the pieces together. It's only because we have this wonderful ladder that we can start to say... hey, I know exactly how bright you are... when we're looking at our favorite galaxies and our most distant super-clusters of galaxies.

Fraser: So, what is one of the most luminous objects that we know of?

Pamela: Well, that's one very simple answer if you want something that lasts more than a few seconds, and that's quasars. An individual quasar... this is the heart of a galaxy that may not be that different from our own Milky Way galaxy, but all galaxies, as far as we know, have super-massive black holes in their centers... black holes that can be as much as a one followed by eight zeroes (100,000,000) times bigger than our sun. So that's ~~ten~~ a hundred million...

Fraser: Hundred million... one billion... yeah, they can be a hundred million to a billion times more massive than the sun, right?

Pamela: Yeah, so we have reached the point where we have to add so many zeroes to things that we start talking in scientific notation. So, these black holes are 10^8 times bigger than our sun, in many cases. Now when an object falls into one of these giant black holes, it gets shredded to bits. Not only does it get shredded to bits, but it gets accelerated violently as it gets shredded to bits. And if a whole lot of stuff is falling in at once, as it tries to accelerate in, there's this whole process involving angular momentum which is mathematically complicated, but the core piece of information is that it has to dump energy. It dumps a lot of this energy as light. So one of these quasars... one of these angry feeding black holes in the center of the galaxy... they can be by themselves a hundred times brighter than our Milky Way. Not brighter than our sun, our entire galaxy. So, that is to say nothing else, a massively bright object.

Fraser: And yet, they're so incredibly far away that you need the Hubble Space Telescope to see them.

Pamela: Not all of them...

Fraser: No, no, no... but you need a good telescope to see them. Even though they are the most luminous objects in the universe, you can't see any with your eyes.

Pamela: There is one exception. I, personally, when I look through telescopes my eyes are kind of bad... I'm one of those people who in dark skies can see like 5th magnitude on a good day. But there's one quasar that is in the magnitude 12 range that you can go out and you can actually see with your own eyes...

Fraser: In a telescope...

Pamela: In a backyard telescope... you do need a telescope somewhere.

Fraser: Right, right. But you're not going to see it with your own eyes... the unaided eye.

Pamela: No, no. You do need a telescope. This is 3C 273. It's one of the nearest... it's one of the brighter... in terms of objects in the sky... apparent brightness—we don't know absolute brightness. But these are really fascinating objects. So for things that last more than a minute or two, they're pretty impressive.

Fraser: And the most luminous object in our galaxy?

Pamela: In our galaxy is probably going to be one of the newborn stars. They actually just recently found a star that is 250, they think, solar masses in size.

Fraser: Which is impossible...

Pamela: Well, that's what we thought. But the thing is, when they first start forming, it hasn't yet reached the point that it has shed enough mass.

Fraser: Right. I see... so it's so young that it hasn't gotten down to a "possible" mass. So it's now in the process of shedding all that mass.

Pamela: So that's probably the brightest thing out there, and I have to admit I'm currently in the process of counting zeroes on my screen... so we're looking at stars 100 times as massive as the sun are ten million times its brightness. So, these are bright... and luminous... and luminous is what actually matters in this case.

Fraser: Right. It's like Eta Carinae is in that camp. That's a star that you can see...

Pamela: If you're in the Southern Hemisphere....

Fraser: ... with the unaided eye, and it's half the galaxy away. Yet it's a star that you can see. It's quite amazing.

Pamela: And it's worth the telescopic look because there's an amazing nebula around it. And this is where what Fraser and I were just saying about mass loss comes into play. It's shedding its mass because it's a crazy young star doing crazy young star things... like shedding mass in violent outbursts that we don't fully understand.

Fraser: And not exploding...

Pamela: And not exploding yet...

Fraser: Which it should...

Pamela: It will. Maybe not in our lifetime... but I want it to! I want it to!

Fraser: I know. So then how bright is something that's very dim and close? I mean how far down are these things detectable? You say magnitude 30 for Hubble? What is that?

Pamela: That would be a very distant galaxy... that would be a distant small star. Some of the brown dwarfs that seem to be reasonable distances can get that faint.

Fraser: Planets orbiting other stars?

Pamela: Well, that depends on what color your looking in. Spitzer's able to make these planets out. So there, they're heated up by their sun's light... if they're too close to their sun, and they start to become reasonably visible.

Fraser: But would that be Hubble's just getting a couple of photons from an object and that's it?

Pamela: Pretty much. It's really amazing how few photons you're dealing with. One of the things that amazes me, especially as you start to get to the higher energies, is that a good detection might be six photons, but each of those photons carries a huge amount of energy in it for a photon. For high energy, every photon gets counted... and that's pretty amazing.

Fraser: But couldn't they use Hubble, detect one photon, and call that the photon from the most distant galaxy ever recorded?

Pamela: Not so much. So the problem with this is that you run into noise. The universe is filled with these annoying things called cosmic rays, as well. So if you only see a high energy photon, or a visual energy photon, or a photon of any color for that matter... you can't say it's from a distant galaxy or it's from some radioactive decay that happened on the planet Earth and went through the bottom of your telescope.

Fraser: Right... or my television.

Pamela: Right. Exactly.

Fraser: I probably should not get a television that's shooting gamma rays at me... ok, well I think that covers our depth into the brightness... our descent into brightness... so that's great. So as we mentioned at the beginning of the show, this is going to be the last episode for the summer, so if you're getting this and you're wondering... are they stopped producing shows? No, it's just summer. We'll be back in September.

Pamela: And we're hoping to get back to our normal twice a week schedule and fully recover from my travel and everything else that has blighted us.

Fraser: And we hope to see you at DragonCon.

Pamela: See you all there!
Fraser: Alright, thanks, Pamela!
Pamela: See you later, Fraser!